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Maximizing Public Benefits from Toll Facilities with Congestion-Based Tolls

Patrick DeCorla-Souza, AICP
Federal Highway Administration, Washington DC
400 Seventh St. SW, Room 3324, Washington, DC 20590.
Tel: (202)-366-4076. Fax: (202)-366-7696.
E-mail: patrick.decorla-souza@fhwa.dot.gov

Abstract

In congested metropolitan areas, variable toll pricing on currently congested toll facilities can maximize public benefits by eliminating congestion on the facilities during peak periods and reducing traffic diversion to alternate routes during off-peak periods. It will be important to ensure that public concerns are addressed, that those "tolled off" have convenient commuting alternatives and that bondholders are protected from revenue risk. This article presents an innovative approach to address the issues and discusses the benefits to be gained. It then assesses the financial self-sufficiency of a region-wide application of congestion-based tolls on currently toll-free limited access highways.

Road Pricing Concepts

Roadway congestion pricing is an economic concept that is gaining increased acceptance for application in congested metropolitan areas. It includes a group of market-based strategies that involve charging a variable toll for highway use, with the primary intent of managing travel demand so as to reduce or eliminate congestion on the facility or metropolitan road network. In the U.S., roadway congestion pricing, also known as value pricing, has been implemented in two types of situations. First, priced lanes have been created on existing toll-free facilities either by converting High-Occupancy Vehicle (HOV) lanes to High-Occupancy/ Toll (HOT) lanes, or by adding new lanes. Second, variable charges have been introduced on existing toll facilities that previously charged flat tolls. Eight road pricing projects are currently in operation in the U.S., four in each category, as shown in Table 1 (DeCorla-Souza 2004a).

Proposals have been made to extend these pricing concepts to region-wide systems of priced freeways or priced freeway lanes that would maintain free-flowing traffic conditions and provide a running way that allows introduction of high quality express bus or Bus Rapid Transit (BRT) service. A proposal by the Reason Foundation (Poole and Orski 2003) would create a network of priced lanes on existing toll-free roads, using existing HOV lanes and adding new lanes on segments where no HOV lanes exist. Free service would be provided only to authorized buses and vanpools. BRT would operate on the express lanes. Another region-wide road pricing concept, called “Fast and Intertwined Regular” highways or FAIR highways, would convert *all* lanes on existing freeways to priced lanes, provide for discounted tolls for low-income motorists, fund new express bus services, and implement major traffic flow improvements on parallel arterial facilities using Intelligent Transportation Systems (DeCorla-Souza 2005a).

Benefits of Congestion-Based Tolling

Free-flowing traffic conditions can be restored on a limited access highway by introducing a congestion-based toll set at a level to balance demand with supply of road space. Restoring free-flowing traffic on a highway facility can allow efficient operation of existing or new express bus transit services and boost transit ridership. It can also encourage carpooling, if carpools receive preferential treatment. Benefits can be significant even for those who continue to drive solo. Based on certain assumptions shown in Table 2, solo drivers may save $2.60 to $3.40 in travel time and fuel cost savings for an average 10-mile trip.

Generally, all that is needed to restore free-flowing traffic conditions on a congested limited access facility is to reduce traffic volume by about 10 to 20 percent. Taking the mid-point of this range, let us assume that a 15 percent reduction is needed in a particular case.   Typically, a congested tollway may carry about 2,100 vehicles per hour per lane (vphpl). A 15 percent reduction would reduce traffic volume to 1,800 vehicles per hour per lane. Let us assume that an average motorist on the tollway makes a 10-mile trip and currently pays a flat toll of $1.50. The magnitude of the increase in the toll that is needed to reduce traffic to 1,800 vphpl depends on motorists' sensitivity to prices and traffic conditions (i.e., demand elasticity). As the middle column in the third section of Table 2 shows, a toll increase ranging from $0.23 to $2.25 above the flat toll of $1.50 (resulting in a total toll of $1.73 to $3.75 in this example) would be needed to achieve the required 15 percent reduction in traffic, depending on conditions existing during a specific time period and toll price sensitivity.

Motorists’ values of time are distributed over a range.   Motorists with the lowest value of time respond to small toll increases and divert to other modes, routes, or times of the day first. Those with higher values of time (i.e., 85 percent of motorists, in this case) pay and stay on. The actual toll increase will depend on how much the motorist with the lowest value of time, in the range of values for the 85 percent of motorists who pay, values his or her time savings. The magnitude of the toll increase will just equal the monetary value of that motorist’s perceived time and vehicle operating cost savings. Since all other motorists have higher values of time, they value their time savings at a higher rate. So the value to them of their time and vehicle operating cost savings would exceed the monetary increase in the toll by varying amounts, depending on their values of time. The difference is essentially a bonus, formally called a “consumer surplus” by economists.

Revenue gains from the 85 percent remaining tolled vehicles in this example will be in the range of $1.30 to $12.75 per vehicle diverted, i.e., 0.85/ 0.15 times the toll increase range of 23 cents to $2.25, depending on demand elasticity on the facility. Thus, except with extremely high demand elasticities, revenue gains should be far greater than the $1.50 revenue loss from each 10-mile vehicle trip diverted, as shown in the last section of Table 2.

The analysis presented in Table 2 is based on the following assumptions, and may vary, depending on the specifics of a particular toll facility:

- Three plausible scenarios of base peak period traffic volumes per lane per hour.
- Travel speed for a 10-mile trip averaging 30 mph, comprised of one-third (i.e., 3.3 miles) traveled at free flow speeds and the remaining two-thirds (6.7 miles) traveled in stop-and-go breakdown traffic flow conditions.
- Time savings from restoring free-flowing traffic conditions valued based on an average value of time of $10.60 per hour per person (U.S. Department of Transportation 2002) and a conservative estimate of vehicle occupancy of 1.0 for all tolled vehicles.
- Low and high demand elasticity extremes of –0.1 and –1.0, based on the literature (Lee 2000).
- Reduced fuel consumption in free flowing traffic based on the *User Benefit Analysis for Highways Manual* (ECONorthwest *et al* 2003).
- Fuel cost of $2.00 per gallon.

The analysis suggests that the toll authority would not be in danger of losing revenue due to reduced peak period traffic, except in the most extreme case of high demand elasticity. Revenue gains from higher congestion-based peak period tolls would generally exceed losses of revenue from diverted traffic. With higher revenues from market-based toll rates in peak periods, toll authorities would have flexibility to lower toll rates in off-peak periods. This would maximize utilization of spare capacity and minimize unnecessary traffic diversions that may cause congestion on toll-free facilities. For example, while the Dulles Toll Road in the Washington DC metropolitan area has very light traffic in off-peak periods, alternative routes in the corridor remain congested during many of those hours. Reducing off-peak tolls on the Dulles Toll Road could thus have a major impact on congestion on alternative routes during off-peak periods.

There are over 1,900 miles of urban toll facilities in the U.S. However, toll authorities with facilities in congested metropolitan areas have generally not moved to variable pricing schemes on existing toll facilities that have flat tolls, despite the promise of significantly improved operational performance, motorist benefits and additional revenue from congestion-based tolls. The exceptions are limited schemes adopted by a few toll authorities in four states - New York, New Jersey, California, and Florida as shown in Table 1 (DeCorla-Souza 2004a). Where toll rates have been raised in peak periods on existing facilities, operators have not raised tolls to levels that will guarantee free-flowing traffic (with the exception of two HOT lane projects); nor have they attempted to lower tolls in off-peak periods to levels that will reduce diversion to parallel congested facilities.

So the question is: If congestion-based tolls are a good deal for the motorist, for the toll authority and for general traffic flow in the metropolitan area, why have toll authorities not rushed to implement them in the United States?

Issues and Challenges for Existing Toll Facilities

Of course, one answer to the question posed above is: The beneficiaries of this innovative market-based strategy are not fully apprised of the benefits that could accrue to them. A good public information campaign may help. However, there do remain several issues that need to be addressed first.

State legislation may need to be modified to allow congestion-based tolls on existing toll facilities. Another recurring concern has been that covenants on bonds backed by toll revenues would be violated. If toll authorities are to widely adopt variable tolls, they will need help from local and State governments whose citizens would benefit. A reserve fund will need to be set up, or existing reserve funds will need to be enhanced, in order to guarantee the claims of bondholders, funded with contributions from the beneficiaries.

In surveys conducted for the toll authority in Pennsylvania (Wilbur Smith Associates 2003), some members of the commuting public expressed concerns about the impacts of higher commuting costs implied by increased rush hour tolls. However, surveys conducted as part of the Illinois Tollway Value Pricing Study (Resource Systems Group 2003) found that about half of all toll-payers indicated that they would be willing to pay at least twice as much for a free-flowing commute. Thus, perhaps, all that might be needed to alleviate much of the public concern about higher peak tolls is a free-flow "guarantee" such as that provided by the operator of priced lanes in the median of SR 91 in Orange County, CA (Sullivan 2000). The operator of the priced lanes guarantees the congestion reduction benefits from higher tolls, with refunds available to those who do not receive the promised premium service.

One issue that will need to be addressed concerns the operating philosophies of most toll agencies in the U.S. Toll authorities often perceive that they have a mandate to maximize overall usage of their facilities at the lowest possible *monetary* cost to their patrons in the form of tolls (Wilbur Smith Associates 1995). They may perceive higher tolls set to "drive motorists away" from their toll facilities as conflicting with their perceived mandate. Also, it may be hard to convince patrons that their *overall* costs, including toll costs, non-monetary costs (e.g., travel time costs) and vehicle operating costs, would be reduced as a result of the higher tolls. But it is possible to adhere to the perceived mandate of toll agencies to maximize overall usage if variable tolls are set to ensure overall revenue neutrality – off-peak tolls could be discounted so that the revenue reductions would balance any revenue gains from the peak periods. Since the discounted off-peak tolls would also bring in additional off-peak users, overall daily usage may also increase above levels existing with flat tolls. Any increase in congestion caused on alternate toll-free highways in peak periods due to diversions of former tollway users may be balanced by reduced congestion on those facilities in off-peak periods due to traffic that is drawn to the tollway by discounted off-peak tolls.

Toll authorities may be able to increase the level of public acceptance by cooperating with local transit and ridesharing agencies to assure that those who cannot afford the higher tolls have other reasonable commuting alternatives available to them. For example, those who carpool may be provided a guaranteed lower peak period toll rate, no matter how high the market-based peak toll rate needs to be for purposes of managing vehicle demand. Local or State governments could assist with provision of convenient park-and-ride facilities and express bus service, with possible funding assistance from the Federal Transit Administration. Also, a portion of any surplus in toll revenue that may result from congestion-based tolls could be dedicated to support transportation improvements in the corridor.

Implementing Congestion-Based Pricing

Congestion-based tolling that guarantees free-flowing traffic conditions requires two pre-requisites:

- Active real-time monitoring of traffic conditions and management of traffic with varying tolls, set to ensure that traffic levels do not exceed certain thresholds
- Universal electronic payment by all users of the toll facility during the peak periods, with back up toll collection using methods such as license plate recognition.

It will be important to ensure that occasional users and motorists who are visiting the area have easy access to the needed electronic transponders. ATM-type outlets will need to be installed near toll facility entrances to facilitate opening new transponder accounts. During off-peak periods, cash tollbooths may still operate, with a fixed toll rate. Those who wish to avail of discounted off-peak tolls would thus have an incentive to open a transponder account.

To provide an incentive for carpooling in peak periods, vehicles carrying a specified number of occupants could be afforded a flat toll rate. They would need to drive through the appropriate HOV lane at toll plazas to get the discount.

The toll authority could hire private sector expertise to manage traffic and collect tolls. The private operator would set toll rates to ensure that free-flowing traffic service is provided during the rush hours, when pro-active management of traffic flow with variable tolls is needed. Compensation could be based on the number of vehicles provided *free-flowing* service, with lower per vehicle compensation in off-peak periods since active management is less of an issue. The off-peak toll rate would be set high enough to at least cover the marginal costs for maintenance and operations. The toll authority would need to set a realistic lower limit to the off-peak toll rate, in order to protect against large unforeseen revenue losses. Since compensation is based on number of vehicles served, private operators would have an incentive to lower the toll rate up to the lower limit during off-peak hours to maximize vehicles served, if spare capacity is available. This would reduce unnecessary off-peak diversions of traffic to nearby free facilities and the consequent congestion and community impacts.

If the lower limit of the off-peak toll rate is set too low, it is possible that revenues from increased toll rates in the peak may not be sufficient to make up for the loss of revenue due to lower tolls in the off-peak, despite the increased traffic levels that lower off-peak tolls would encourage. A reserve fund would need to be set up to guarantee any shortage, funded with commitments from local, State or Federal sources. Possible Federal sources might include the Federal Highway Administration's Value Pricing Pilot Program, set up to encourage use of variable toll pricing to address congestion problems. Local or State funds for match of Federal funding would not be required, since "toll credits" (i.e., Federal credits allowed to States with toll facilities) could be used in lieu of local match, allowing 100 percent Federal funding. A policy could be set allowing the lower limit of off-peak toll rates to be adjusted upwards by the toll authority if it becomes necessary to dip into the reserve fund due to shortages.

Demonstrating the Concept

Variable tolls to eliminate congestion may be piloted most easily in an existing travel corridor with a tollway. The toll authority could enter into an arrangement with a private partner to implement variable peak period charges to ensure free-flowing traffic conditions. Surplus revenues (if any) could be used to subsidize private vendors or public transit agencies providing new or enhanced transit services or park-and-ride facilities in the corridor.

Moving to the Future: Region-wide Applications

After the benefits of variable toll pricing are successfully demonstrated on existing toll facilities, it will be possible to look to expansion of the toll market by thinking in broader terms about benefits that could be achieved from imposing variable pricing on existing *toll-free* facilities. It will be important for the tolling industry to participate in the development of regional transportation plans through Metropolitan Planning Organizations, to encourage consideration of more widespread tolling.

Could an entire region-wide road pricing/ express bus system be financially self-sufficient, without infusion of tax dollars, thus increasing the opportunity for more private sector involvement? A feasibility study for a network of HOT lanes in the Twin Cities of Minnesota suggests that tolls could pay only 15 percent to 55 percent of the cost of building the lanes (Cambridge Systematics, Inc. 2005). The consultant-recommended system would have a cost recovery ratio of 33 percent. A similar HOT lane system study in Atlanta (Parsons, Brinckerhoff, Quade and Douglas 2005) suggests that, as long as a policy is in place to restrict free service to transit vehicles and carpools with four or more persons, tolls can cover the costs for technology associated with HOT lane operations as well as operations and maintenance costs, but not costs for building infrastructure such as new highway lanes. Poole and Orski (2003) suggest that the type of region-wide BRT/HOT system advocated by them will not be financially self-sufficient. The main reason is the high cost of new construction for lanes to be added on segments where HOV lanes do not currently exist, for additional shoulders and barriers between HOT and regular lanes, and for direct access ramps to ensure safe conditions for entry and exit from the lanes. Revenues generated are inadequate to cover all of the capital costs for highway construction, let alone the continuing maintenance and operation costs. Transit system costs, other than the "fixed guideway" costs (i.e., highway lane construction costs) would need to be supported entirely by fares and tax dollars.

Metropolitan areas could overcome the financial deficit issues in Poole and Orski's proposals, and at the same time provide a significant increase in social benefits, by moving to congestion-based pricing on *all* lanes of the existing toll-free limited access highway system *in peak periods only* using the FAIR highway network concept (DeCorla-Souza 2004b, 2005a). New *fare-free* express bus services could be introduced on the priced network, and park-and-ride facilities could be provided for transit riders and carpoolers, to ensure that new viable alternatives to solo commuting are available. Major traffic flow improvements could be implemented on parallel arterial facilities using Intelligent Transportation Systems, in order to alleviate the effects of possible traffic diversions. No tolls would be charged in off-peak periods, because off-peak tolls may actually reduce social benefits if spare capacity is available and demand management is not necessary. A peak period commuter would have several options:

a) Pay a relatively low (about $1.00) toll for the pleasure of driving alone in free-flowing traffic.
b) Join a carpool and enjoy a free-flowing ride for a "lower" price by sharing the cost of the market-based toll. (No discounts would be provided, to reduce enforcement problems).
c) Take a free express bus, and pay market rates for shuttle service by private providers at the destination end (if needed).

The concept was assessed with regard to financial self-sufficiency using a prototypical freeway network in a major metropolitan area with a population of more than 3 million. Table 3 provides estimates of vehicle miles of travel (VMT) that would be subjected to tolls and resulting toll revenue. The estimates are based on the following:

- The prototypical freeway network is assumed to be subjected to 6 hours of congestion, and 33 percent of *daily* freeway travel is assumed to be subjected to congested conditions in the 6-hour peak period that would warrant the use of road pricing to manage demand. This ensures a conservative estimate of toll revenue. In 2003, the average daily congested travel period in major U.S. metropolitan areas amounted to about six and one-half hours, and percent of *daily* travel under congested conditions amounted to about 40 percent (Texas Transportation Institute 2004).
- About 50 percent of daily traffic occurs in peak periods. Assuming that little congestion occurs in off-peak periods, the 33 percent of *daily* traffic that is congested translates to about two-thirds (67 percent) of peak period traffic, or 6.7 miles of a 10-mile freeway trip in peak periods.
- Revenue from the tolled traffic is estimated by multiplying traffic in peak periods that would be subjected to tolls by the respective average toll rates for passenger vehicles and trucks, which are estimated based on HOT lane experience (DeCorla-Souza 2004b). Tolls are assumed to be charged on 250 working days each year.

The average peak period toll for a 10-mile freeway trip, two-thirds of which would be subject to a toll, would be $1.05 for passenger cars and $2.70 for trucks. Since a heavy truck on average consumes two to three times the lane capacity of a passenger car in free-flowing traffic, tolls for trucks are estimated to average 2.5 times the toll rate for passenger cars. A market research study conducted as part of the HOT lanes system study in Atlanta (Parsons, Brinckerhoff, Quade and Douglas 2005) suggests that a majority of motorists would be willing to pay between $0.50 and $2.00 for a congestion-free commute trip. Total region-wide revenues are estimated at about $470 million annually. Total region-wide annualized costs would amount to about $285 million, as shown in Table 4. A comparison of system-wide revenues to system-wide costs suggests that there will be a surplus of revenue of about $185 million annually. This would provide a cushion that could reduce financing costs in the capital markets. It would also provide a source of revenue for new investments to address critical transportation needs.

Conclusions

Introducing congestion-based pricing on existing toll facilities as well as existing toll-free highway systems would provide major benefits for highway users and the general public through reduced congestion. It would also provide new funding for investment in transportation facilities and services in congested metropolitan areas. A pilot demonstration on a major existing toll highway would help considerably in gaining public understanding and acceptance of this innovative concept. An analysis of a region-wide application of the concept to currently toll-free limited access highways in a prototypical metropolitan area suggests that it would generate sufficient new revenues to pay for toll collection operations as well as mobility improvements, including new fare-free express bus service, and arterial and freeway network management and operations. Surpluses will also be generated, providing a source of revenue for new investments to address critical transportation needs.

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AUTHOR INFORMATION

Patrick DeCorla-Souza is a Team Leader at the Federal Highway Administration, Office of Transportation Policy Studies. He manages the FHWA Value Pricing Pilot Program.

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Table.1 Value Pricing Projects by Type- Operational Projects

State	Locality/ Year Implemented	Project
Priced Lanes		
California	Orange County/ 1995	Express Lanes on SR91: Toll varies from $1.05 to $7.00 depending on traffic demand
California	San Diego/ 1996 (low tech) 1998 (electronic tolls)	HOT lanes on I-15: Toll varies dynamically from 50 cents to $4 depending on traffic demand.
Texas	Houston/ 1998	HOT lanes on Katy Freeway (I-10): $2 toll charged to two-person carpools in the peak hour of the peak period; 3-person and larger carpools are free
Texas	Houston/ 2000	HOT lanes on US 290: Toll policy same as for I-10, but applies only to morning peak period
Variable Pricing on Toll Facilities		
California	Orange County/ 2002	Peak pricing on the San Joaquin Hills Toll Road: Toll surcharge of 25 cents during peak period at several entrances to the facility; toll surcharge of 50 cents at one mainline toll plaza
Florida	Lee County/ 1998	Variable pricing of two bridges: 50 percent toll discount (amounting to 25 cents) offered in shoulders of the peak periods
New York	New York metropolitan area/ 2001	Variable tolls on Hudson River crossings: Off-peak tolls discounted by 20% relative to peak period tolls, i.e., $4 vs. $5
New Jersey	Statewide/ 2000	Variable tolls on New Jersey Turnpike: Peak period toll exceeds off-peak toll by 12.4%; for the entire 238 km (148 mile) length, off-peak toll is $4.85 vs. peak toll of $5.45

TABLE 2. ESTIMATES OF POTENTIAL IMPACTS OF CONGESTION-BASED TOLLS

Average time saved per freeway trip			
Base peak period average travel speed (mph)	30		
Average freeway trip length (miles)	10		
Travel time for average freeway trip (minutes)	20		
Average speed with congestion-based tolls	60		
Travel time for average freeway trip (minutes)	10		
Travel time saved on average trip (minutes)	10		
	Small car	**Big car**	**SUV**
Cost savings per freeway trip			
Average value of time per hour saved	$10.60		
Value of time saved	$1.77	$1.77	$1.77
Fuel saved per minute of delay (gallons)	0.042	0.066	0.083
Fuel cost per gallon	$2.00		
Value of fuel saved per minute of delay reduced	$0.08	$0.13	$0.17
Value of fuel saved over a 10-mile trip	$0.84	$1.32	$1.66
Total value of time and fuel savings	$2.61	$3.09	$3.43
	Traffic Volume Level		
	Moderate	**High**	**Extreme**
Range of Toll Rates			
Assumed base peak traffic per hour per lane	2000	2120	2250
Max. traffic for guaranteed free-flow conditions	1800	1800	1800
Percent traffic reduction needed	10%	15%	20%
Number of vehicles diverted per lane per hour	200	320	450
Base toll	$1.50	$1.50	$1.50
*A. Low demand elasticity**	-0.1	-0.1	-0.1
Percent increase in toll to achieve reduction	100%	150%	200%
Actual increase in toll	$1.50	$2.25	$3.00
Total peak period toll	$3.00	$3.75	$4.50
*B. Extremely high demand elasticity**	-1.0	-1.0	-1.0
Percent increase in toll to achieve reduction	10%	15%	20%
Actual increase in toll	$0.15	$0.23	$0.30
Total peak period toll	$1.65	$1.73	$1.80

Revenue Gains vs. Losses (per lane per hour)

A. Low demand elasticity			
Revenue gains from tolled vehicles	$2,700	$4,050	$5,400
Revenue losses from diverted vehicles	$300	$480	$675
Net change in revenue	$2,400	$3,570	$4,725
B. Extremely high demand elasticity			
Revenue gains from tolled vehicles	$270	$405	$540
Revenue losses from diverted vehicles	$300	$480	$675
Net change in revenue	-$30	-$75	-$135

*The amount of the toll increase needed to achieve a reduction in traffic depends on demand elasticity, which generally varies from a low of –0.1 to a high of –1.0. A demand elasticity of –0.1 means that a 1 percent toll increase is needed to achieve a traffic reduction of 0.1 percent. Likewise, a demand elasticity of –1.0 means that a 1 percent increase in the toll would result in a reduction in traffic of 1 percent.

TABLE 3. REGION-WIDE FAIR HIGHWAY NETWORK: TRAVEL DEMAND AND REVENUE

Region-wide daily highway vehicle miles of travel (VMT):	
Total daily freeway VMT ('000)	36,200
Percent of freeway VMT that is subjected to congestion	33%
Daily freeway VMT subjected to congestion ('000)	11,946
Estimated percent VMT reduction due to pricing	10%
Estimated freeway VMT that will be tolled ('000)	10,751
Percent VMT by trucks in peak periods on freeways	10%
Tolled VMT by trucks in peak periods on freeways ('000)	1,075
Tolled VMT by passenger vehicles in peak periods on freeways ('000)	9,676
Estimate of Toll Revenue	
Estimate of toll rate per mile for trucks	$0.40
Estimate of toll rate per mile for passenger cars	$0.15
Daily toll revenue from trucks ('000)	$430
Daily toll revenue from passenger cars ('000)	$1,451
Daily toll revenue total ('000)	$1,881
Number of days tolling is in effect	250
Annual toll revenue ('000)	**$470,374**

TABLE 4. ANNUALIZED COSTS VS. ANNUAL REVENUES (million $)

Capital costs for toll collection/credit systems	$10.0
Operations cost	$80.6
Highway lane construction costs	$0.0
Express bus service cost	$138.0
Park-and-ride facilities	$46.4
Management and operations of arterial network	$10.0
Total annual costs	**$285.0**
Revenues	**$470.4**
Surplus	**$185.3**